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TITLE: CONTAINMENT BUCKLING PROGRAM

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CONTAINMENT BUCKLING PROGRAM

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The Containment Buckling program at the Los Alamos National Laboratory is aimed at evaluating the adequacy of the current design procedures for free standing steel nuclear containment shells against static and dynamic structural instability. Such buckling behavior will typically produce large displacements in the shell wall that will potentially violate seals around hatches and penetrations, or even produce puncture or tearing of the shell wall resulting in a loss of containment function. The ultimate goal of the program is to provide NRC with a basis for evaluating the associated licensing issues and to recommend appropriate changes and additions to the NRC Review Criteria.

The program is proceeding in three basic phases. Phase I was an evaluation of the possibility of the ASME Area Replacement Method for Reinforcing around circular penetrations as also being a means to insure against buckling. This phase has been completed and is reported in detail in Ref. 1.

In Phase I steel cylinders simulating containment shells were fabricated to one-sixtieth actual size. A number of these cylinders were left unpenetrated; others were fabricated with a scaled penetration and then reinforced to various amounts according to the ASME code rules; none were stiffened by rings as is normal for containment vessels. The cylinders were checked for roundness, end parallelism, variation in wall thickness, and other imperfections, then were instrumented with strain gages. After careful shimming between the cylinder and testing machine to help approach uniform end loading, the cylinder was loaded to failure. Figure 1 shows one of the penetrated and reinforced cylinders after testing.

These experiments clearly showed that fabrication imperfections dominated the buckling failure of steel cylinders. For example, unpenetrated cylinders buckled at a load considerably lower than the value predicted for perfect cylinders. Cylinders with penetrations but no reinforcement failed at essentially the same load as unpenetrated cylinders; that is, the effect of the hole was apparently too small to cause buckling before the shell failed from other imperfections. Imperfections are, thus, felt to be the main reason for the considerable scatter in the data for the steel cylinders shown in Fig. 2 (dots). For comparison, data (triangles) are also plotted from study of a reusable Mylar shell. Because the Mylar cylinder was of high enough qualtiy that the penetration lowered the buckling load, these data show little scatter as the buckling load increases with reinforcement. In this figure the amount of reinforcement is expressed as a percentage of that recommended in the ASME code for reinforced penetrations. The main conclusion from this study is that by reinforcing a circular penetration according to the ASME Area Replacement Method, the buckling load will be increased, but not necessarily back up to the unpenetrated value.

Phase II is a series of ring stiffened experiments that will be used to benchmark computer code buckling predictive capability. This phase is being carried out in coordination with Lockheed Palo Alto Research Laboratory's analytical studies of the same geometric configurations, and with the cooporation of Chicago Bridge and Iron who supplied typical penetration sizes and framing details in accordance with industry practice. Analytical predictions have been partially completed and experiments are now underway on these shells. Figure 3 shows a photograph of one of the "baseline" benchmark test cylinders that are currently undergoing imperfection measurements and instrumentation. The baseline benchmark test cylinders do not have penetrations.

Current plans call for loading the cylinder with a concentrated load applied at one-half the radius through a relatively rigid top loading plate and end ring, resulting in a nonaxisymmetric buckling mode. The present analytical predictions by Lockheed are that a nonsymmetric "elephants" foot local buckling pattern will develop in the 2.5 in. bay between the seventh and eighth ring from the top of the cylinder at a load of 17,840 lb.

Figure 4 shows plans for one of the typical follow-on test cylinders that are currently being fabricated that will have framed and reinforced penetrations. Penetrations fall into the category of interrupting no ring stiffeners, to interrupting up to three rings. Framing details can vary, but the basic philosophy is to frame the penetration in such a manner as to make the ring "look" continuous by replacing the area and bending stiffness of the interrupted rings. Reinforcing is in accordance with applicable ASME code requirements. Credit is also taken for the nozzle neck as part of the reinforcing up to one shell wall thickness. Neck area greater than this appears to have an insignificant effect. Four of these cylinders, one for each type of penetration, are now under construction.

The third phase of the program is to study and develop recommendations on the dynamic buckling behavior of steel containments. Primary loads of interest are both earthquake and asymmetric accidental internal pressure transients.

There is no doubt that shell "buckling" or, at least a large displacement buckling type of failure that resembles those obtained statically, will occur at some value of dynamic loading (as evidenced in the numerous failed tanks in earthquake prone regions, for example). Beyond this, a dynamic buckling load is difficult to define. The generally accepted definition is the dynamic loading that will cause a large increase in displacement with little or no increase in acceleration magnitude. From experimental data on Lexan or Mylar shells that can "snap through" and recover, such displacement patterns can be observed to occur at a given magnitude of acceleration during sinusoidal forcing tests. For a steel shell, only one will occur before failure and a "different" shell is obtained. For this reason, studying this phenomena using Lexan or Mylar is attractive.

The currently accepted design practice for these loadings as they influence buckling is the "freezing in time" analysis method. The transient stresses in the containment shells are first calculated and then a static bifurcation analysis is performed using the stress field from the (usually linear) transient analysis. The "freezing in time" technique has not been subjected to rigorous evaluation except for a few isolated cases.

The details of the technique vary from investigation to investigation. The simplest method is to choose an appropriate time, based on engineering judgement and locate the largest compressive membrane stresses. These stresses are assumed to act uniformally over the complete shell as a prebuckling stress field and the buckling stress is then found from either a closed form solution, or an empirical formula, or a numerical analysis.

Other variations are to use the complete spatial distribution of the membrane stresses from the transient analysis and then perform a bifurcation analysis at various "snapshots" in time. Still another variation is to include the prebuckling bending stresses in the bifurcation analysis, although they usually have little effect on buckling.

The transient analysis can be both materially and geometrically nonlinear, although geometric nonlinearities probably have little effect. Shallow spherical caps under transient pressure are an exception. Plasticity has not been investigated to any extent in this type of problem. Realistic end conditions, discrete stiffeners, penetrations, attached masses, etc. probably should be but are not always included in the transient analysis.

Our program is proceeding along the line of a joint analytical/experimental effort, using Lexan as a model material in an effort to study the "freezing in time" technique. We are studying generic containment-like models, ultimately including ring stiffeners, penetrations, and significant attached masses. It is surprising that this method of analysis has gained acceptance without evidence being presented to verify its accuracy and assessing the limits of its applicability. We believe that this phase of the program may be the most important contribution to both NRC licensing criteria and the buckling literature in general.

REFERENCES

1. J. G. Bennett, R. C. Dove and T. A. Butler, "An Investigation of Buckling of Steel Cylinders with Circular Cutouts Reinforced in Accordance with ASME Rules," Los Alamos National Laboratory report NUREG/CR-2165 (LA-8853-MS) June 1981

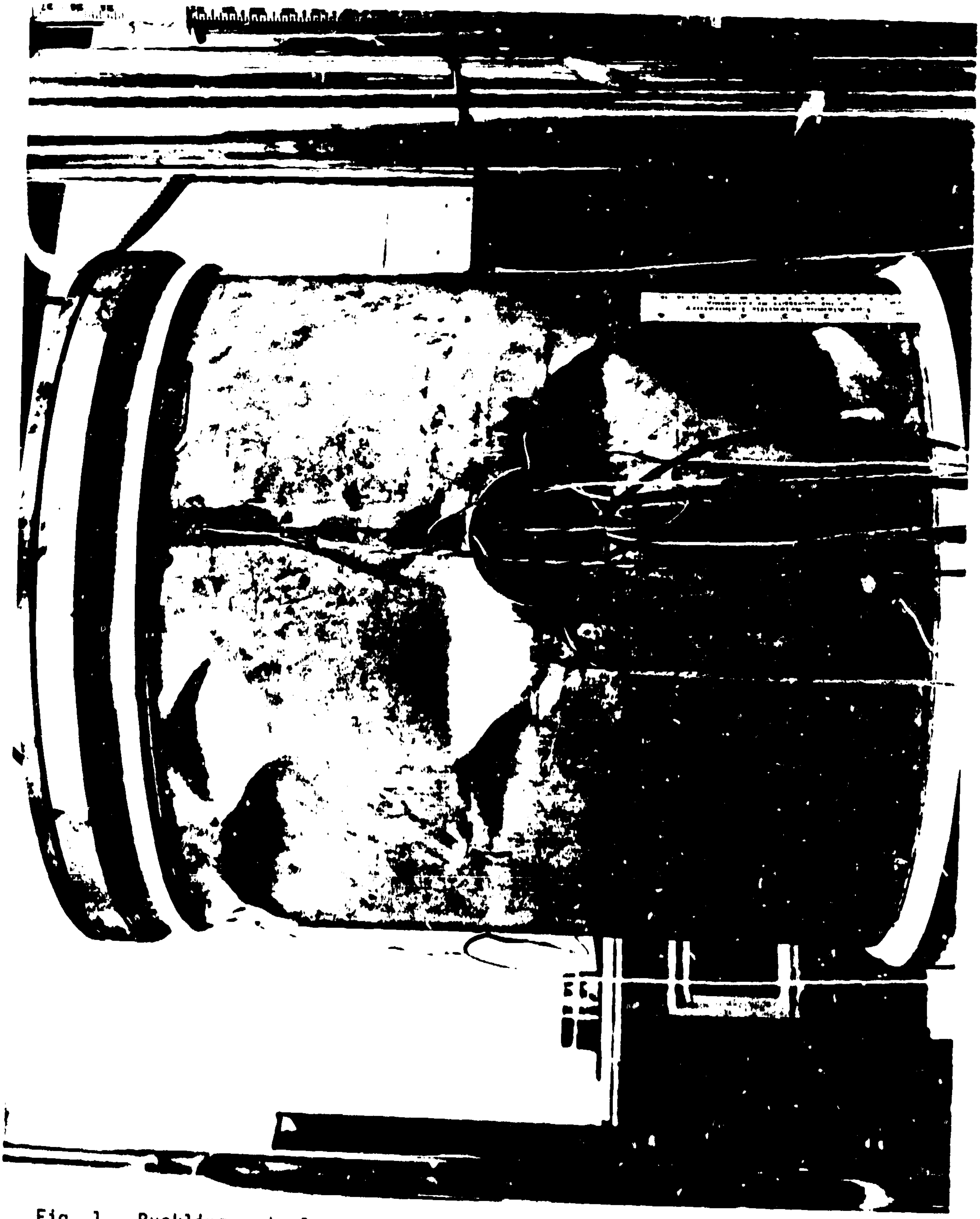

Fig. 1. Buckling mode for a penetrated and reinforced cylinder with 25% required reinforcement.

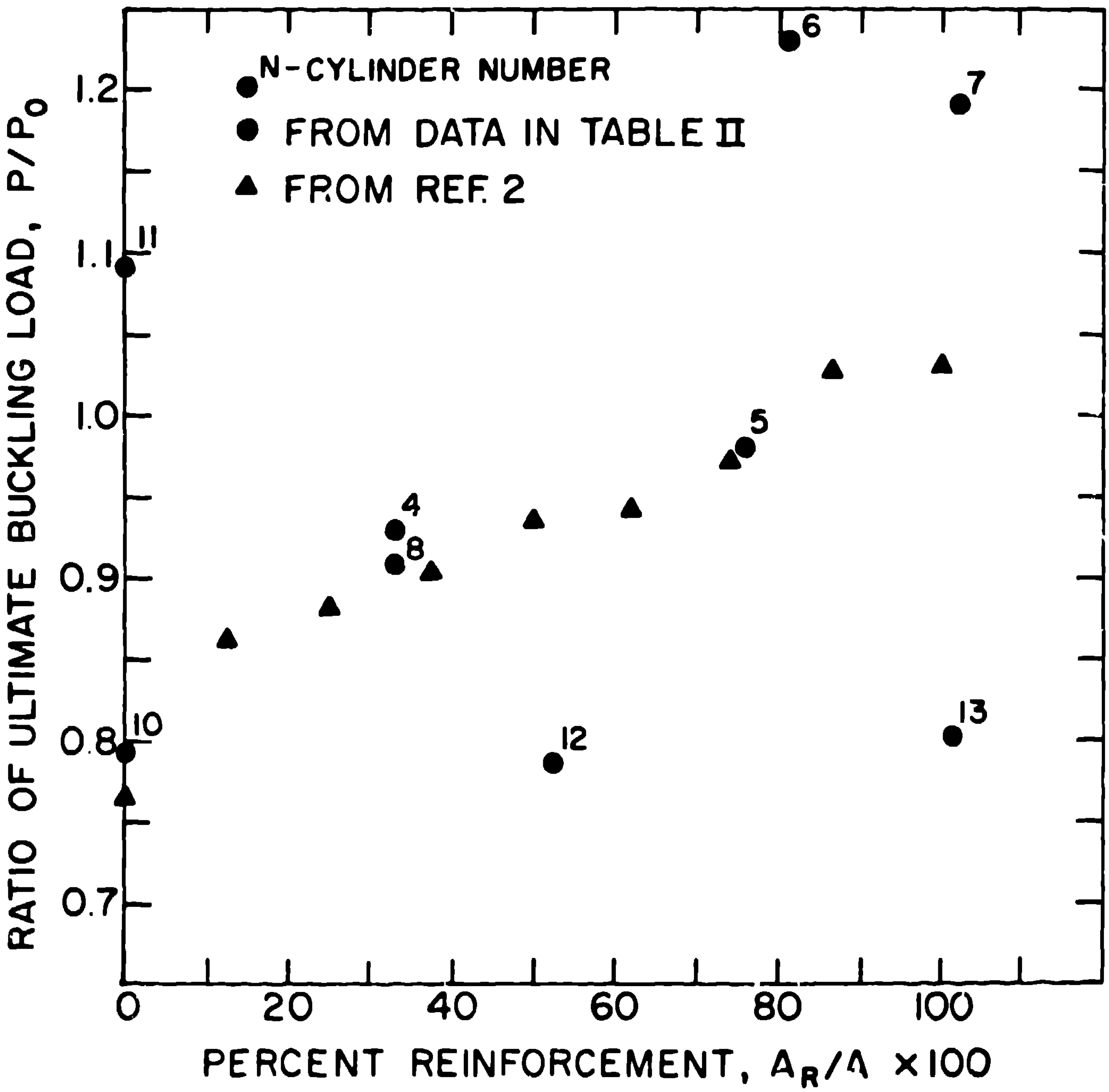

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Fig. 2. Experimental data showing the effort of reinforcement on the buckling load.

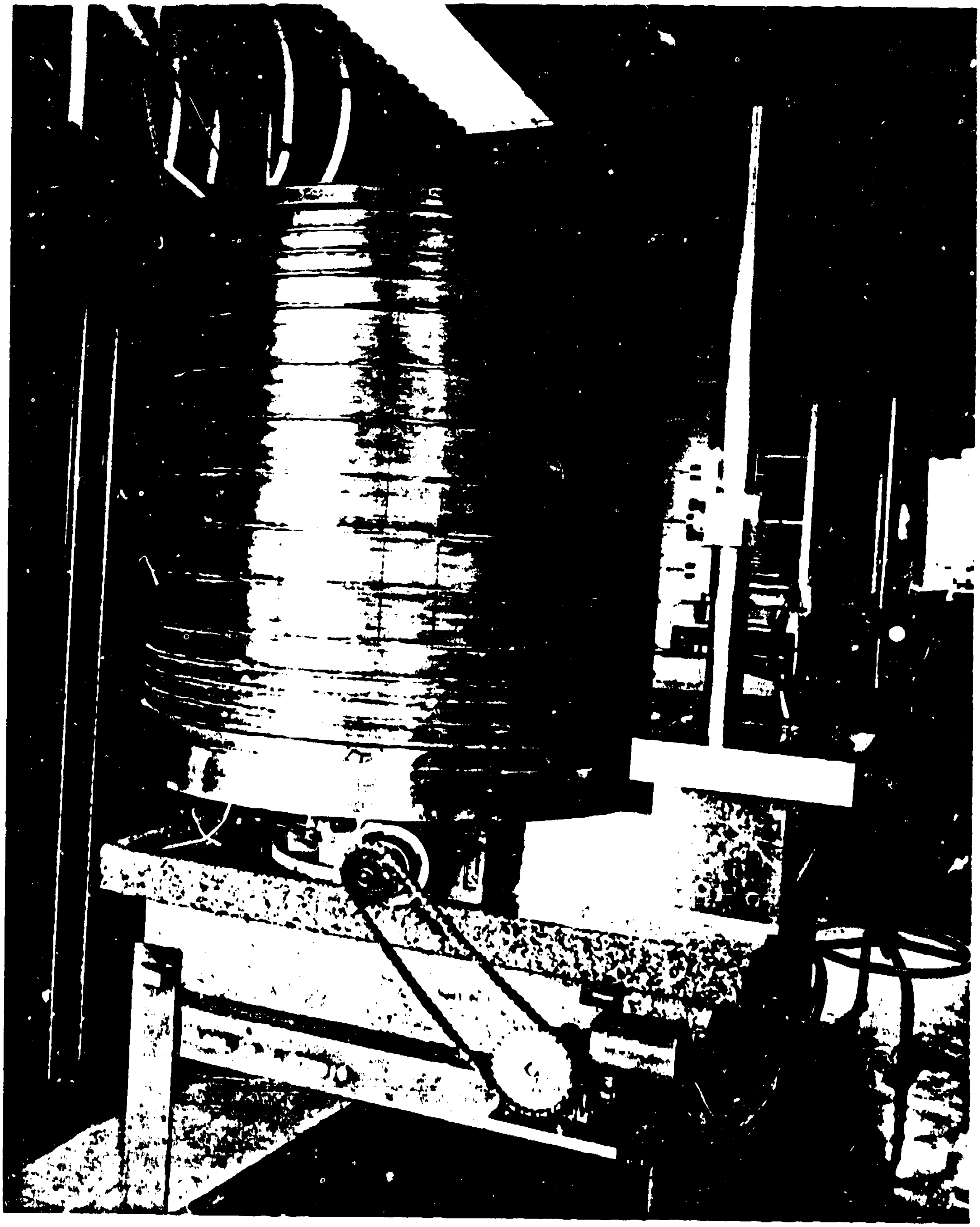

Fig. 3. Baseline benchmark test cylinder undergoing imperfection measurements.

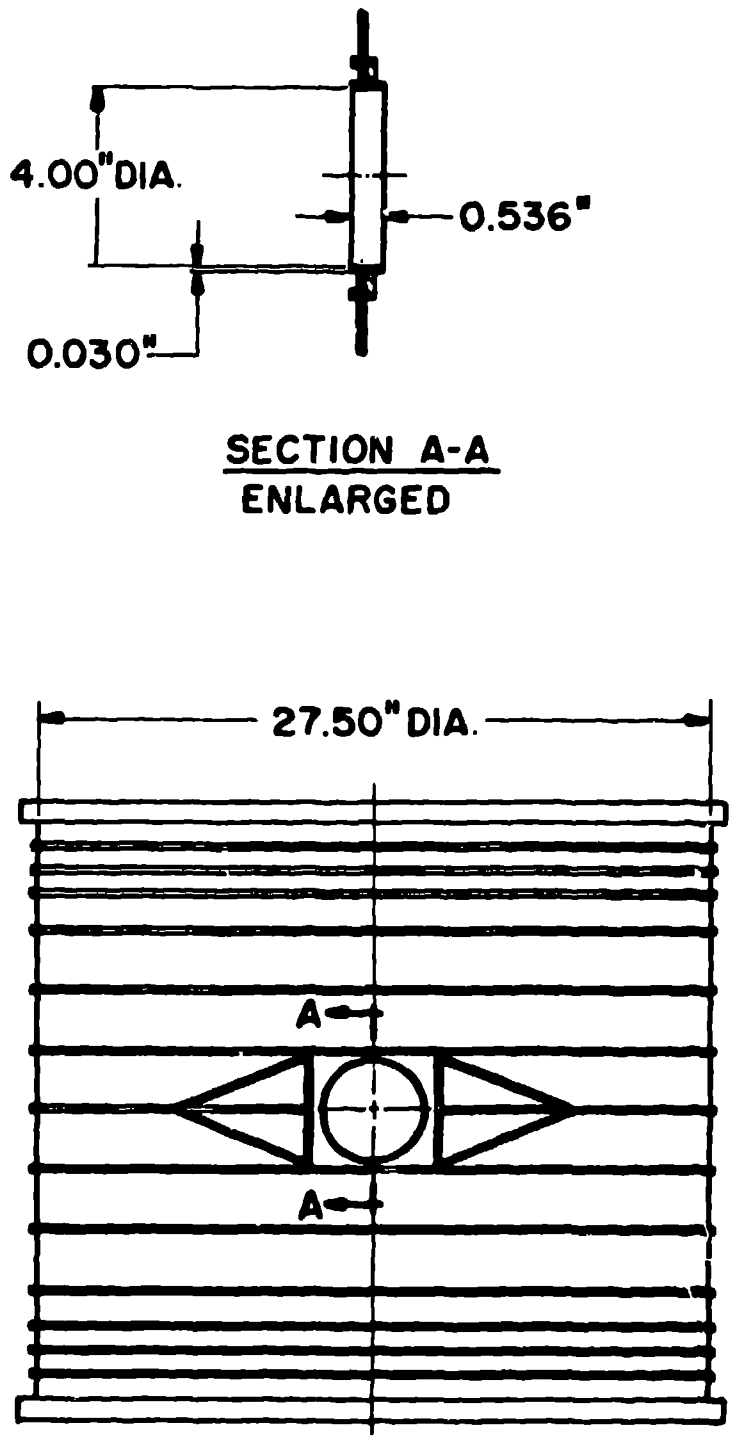

Fig. 4. Framing and construction plans for a test cylinder that has two interrupted rings.